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Dear Dr. Maxwell:

I am enclosing three copies of our Final Technical Report for the project: "Collisional Dynamics of Perturbed Particle Disks in the Solar System," NASA Award No. NAGW-929, 7/1/86 - 12/31/89.

Also attached is an abbreviated (but detailed) bibliography (last three years).

Thank you very much for your support in our research efforts.

Sincerely yours,

Bill Roberts

William W. Roberts, Jr.
Professor
Principal Investigator

(NASA-CR-193584) COLLISIONAL DYNAMICS OF PERTURBED PARTICLE DISKS IN THE SOLAR SYSTEM Final Technical Report, 1 Jul. 1986 - 31 Dec. 1989 (Virginia Univ.) 7 p

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FINAL TECHNICAL REPORT

COLLISIONAL DYNAMICS OF PERTURBED PARTICLE DISKS IN THE SOLAR SYSTEM

William W. Roberts, Jr., Principal Investigator, University of Virginia
NASA Award No. NAGW-929, 7-1-86 - 12-31-89

Theoretical and computational studies have been carried out on galactic and planetary disks under NASA Grant NAGW-929. With the goal of addressing important open questions centered on galactic structure, the cloudy interstellar medium, giant molecular clouds, and star formation in galactic disks and the collisional dynamics of perturbed particulate matter in planetary disks, we have focused largely on the self-gravitational effects, dissipative effects, and collisional dynamics of 'cloud-particle' disks.

N-body, 'cloud-particle' computational algorithms have been developed for the purpose of isolating the role of gaseous self gravity from the roles of other dominant physical mechanisms and dynamical processes, e.g. the collisional dynamics and dissipative processes (Roberts and Hausman, 1984; Roberts and Stewart, 1987; Roberts, Adler, and Stewart, 1988; Roberts and Adler, 1988, 1989, 1990; Roberts, Lowe, and Adler, 1990; and Roberts, 1990 [also see the attached Abbreviated Bibliography]). The efforts focused largely on galactic disks show that observational constraints provide stringent tests of the numerical simulation techniques developed. Self gravitational effects of the galactic interstellar medium's gas clouds are included by means of Fourier Transform techniques, adapted from those developed by Miller (1976), Miller and Smith (1979a, b), and Smith and Miller (1986).

In our computational studies, gaseous self-gravity is found to act on the large scale in galactic spirals to enhance the overall collective gravitational field driving the gaseous response and thus help maintain the global spiral structure. On local scales, gaseous self-gravity is found to aid the formation and assembling of massive aggregations of clouds into giant cloud complexes, spurs, and feather-like features. Such transient features give rise to local disorder within the global spiral structure and blur the global coherence.

The important question of the mutual coexistence of these local and global structures is a fundamental issue that has been uncovered and has been largely motivated through the results of the present work under NASA Grant NAGW-929. Our computational work has provided high resolution results at levels beyond those currently attainable by continuum codes which thus far have not been able to isolate or delineate important local structures and corresponding dominant processes and phenomena on local scales. We have been able to develop these high resolution capabilities successfully toward the goal of reproducing the characteristics and realistically-disorderly appearances of real galactic disks.

Other important questions and issues have been motivated in large part by the present work under NASA Grant NAGW-929. For example, how important is the role played by the gaseous component in regard to the fundamental issues of stability and persistence? Striking is the local raggedness and patchiness of the computed distribution of gas and young stellar associations under the influence of gaseous self gravitational effects. To what extent do these continually-evolving, transient manifestations on local scales naturally perturb the global spiral structure? To what extent do they enhance the global structure? In the present studies, local spurs, feathers, and secondary features continually break apart and reform as the looselyassociated aggregations and giant complexes of clouds continually disassemble and reassemble over time. Can the global spiral structure persist, in particular for cases of higher gas mass fractions, where gaseous self gravity is even more prominent on local scales? If so, under what conditions?

It may be possible to address these questions and issues in future investigations, made possible through the high resolution computational algorithms developed in the present work under NASA Grant NAGW-929. Model galaxies should be considered in which the local gas mass fraction spans the full range of physically realistic galactic disks. It will be critical to determine the degrees in various cases to which the gaseous component can play "active" and "passive" roles in global spiral structures, bar structures, and ring structures as well as the degree with which gas cloud aggregations and complexes interact on local scales.

Nonlinear effects emerging in part from the nonlinear dynamical nature of the particulate matter in the present work are seen to be important. In applications to global galactic spirals, the density distribution of the self-gravitating cloud system is often found to be strongly-peaked with peak-to-mean values typically 3:1 and arm-to-interarm contrasts typically 6:1, with arm thicknesses on the order of a kpc. A sharp deceleration in the $u_\perp$ velocity component across a spiral arm from supersonic to subsonic is also a striking manifestation in the self-gravitating computations, with much-more-gradual-characteristic-rise downstream. Such skewness is less apparent in the density distribution, with the density rise occurring over the broad shock width of a number of collisional mean free paths. Effective synergism of the present high-resolution computational studies with corresponding high resolution observational studies (e.g., for M 81 [Bash and Kaufman, 1986; Kaufman and Bash, 1986; Kaufman, et. al., 1987] and M 51 [Allen, et. al., 1986; Lo, et. al., 1987; Tilanus, et. al., 1988; Tilanus and Allen, 1988] should help determine to what degree these characteristics apply or do not apply in real galaxies and to what degree our current understanding requires further refinement (e.g., magnetic cloud collision fronts suggested by Elmegreen, 1988). Such synergism is expected to have strong impact toward deeper understanding of star formation and the underlying dynamical processes on important intermediate galactic scales. For the first time at high resolution, definitive tests should be possible, utilizing and comparing in considerable detail these tracers in the observations and their counterparts in the computational work.

Similarly important open questions still need to be addressed on the collisional evolution of the "particulate" matter in planetary disks and ring systems. Many of the most surprising features in the Saturnian ring system, e.g. narrow rings, gaps, and wavy edges, are believed to be caused by the gravitational perturbations of small moonlets or shepherding satellites (Cuzzi et al. 1984). The shepherding satellites which confine Saturn's F ring have actually been observed and there is strong circumstantial evidence for moonlets orbiting inside Encke's division (Cuzzi and Scargle 1985, Showalter et al. 1986). Several researchers have suggested that the unexplained optical depth fluctuations in the B ring may in part reflect the incomplete shepherding action of undetected moonlets (Henon 1981, Lissauer et al. 1981, Borderies et al. 1984). Although the dynamical response of a collisionless disk to a small perturbing mass was already studied by Julian and Toomre (1966), the collisional evolution of perturbed particulate disks has only recently begun to be analyzed (Borderies et al. 1983, 1985; Shu et al. 1985a, b). Given the huge variety of remarkable, but yet still only partly understood, features in planetary rings (Cuzzi et al. 1984), more detailed modeling of moonlet-perturbed disks is clearly needed to interpret the existing observations. In particular, major thrusts are necessary for deeper understanding of the effects of collisions on observable features of moonlet-perturbed regions of planetary rings (Showalter and Burns 1982). Work on the wavy edges of the Encke gap by Cuzzi and Scargle (1985) and Showalter et al. (1986) have pointed toward the need for detailed modeling of the damping due to collisions in order to more fully understand the observations.

Through utilization of the computational algorithms largely developed in the current work, future efforts may be possible, for example, on Saturn's F ring between Pandora and Prometheus in which sparsely distributed "parent objects" may be sporadically releasing a regolith of particles when they collide with each other, while continually sweeping up each others' debris in the interval between collisions (Cuzzi and Burns, 1988). The numerical simulation techniques developed in the present work under NASA Grant NAGW-929 should be capable of simulating upwards of 30,000 ring particles. Meaningful tests of analytical formulations for particle disk dynamics (Shu and Stewart, 1985) may be possible simultaneously.

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